Quantitative Classification Of Subjective Time Perception Into Neutral, Compression, And Expansion Patterns Using The Human Concentration Counter

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Abstract

Subjective time perception varies markedly across individuals and is strongly influenced by attentional and cognitive processes. However, its objective measurement remains methodologically challenging due to reliance on self-report, software-based tasks, and susceptibility to visual feedback and counting strategies. The present study introduces a hardware-based, quantitative framework for classifying subjective time perception using the Human Concentration Counter (HCC).

In an experimental cross-sectional design, 237 adult participants performed a prospective time estimation task for a 60-second target duration under a hidden-display condition. Objective time was recorded internally by the HCC, and subjective distortion was quantified using Percentage Time Error (%TE). Participants were classified into Neutral ($|\%TE| \leq 5\%$), Compression ($\%TE < -5\%$), and Expansion ($\%TE > +5\%$) categories.

Results revealed substantial inter-individual variability. Neutral perception was observed in 41.8% of participants, while 33.3% exhibited time compression and 24.9% showed time expansion. Compressors underestimated time by $-23.70 \pm 15.23\%$, whereas Expanders overestimated time by $+14.31 \pm 13.36\%$. Group differences were highly significant (ANOVA: $F = 207.52$, $p < 1 \times 10^{-52}$), confirming robust separation between perceptual patterns.

The findings demonstrate that subjective time perception can be reliably categorized using objective, hardware-based measurements. The proposed HCC-based classification framework offers a reproducible and methodologically robust approach for studying temporal cognition and individual differences in internal timekeeping.

Keywords: Subjective time perception; Human Concentration Counter; Time compression; Time expansion; Percentage time error; Temporal cognition; Quantitative classification

1. Introduction

1.1 Subjective Time Perception

Subjective time perception refers to the internal experience of duration in the absence of external temporal cues. Unlike objective clock time, which progresses uniformly and can be measured precisely, subjective time is cognitively constructed and therefore inherently variable across individuals and contexts [1,2]. Human judgments of duration are strongly influenced by attentional allocation, concentration, emotional state, and arousal, leading to systematic deviations from physical time [4].

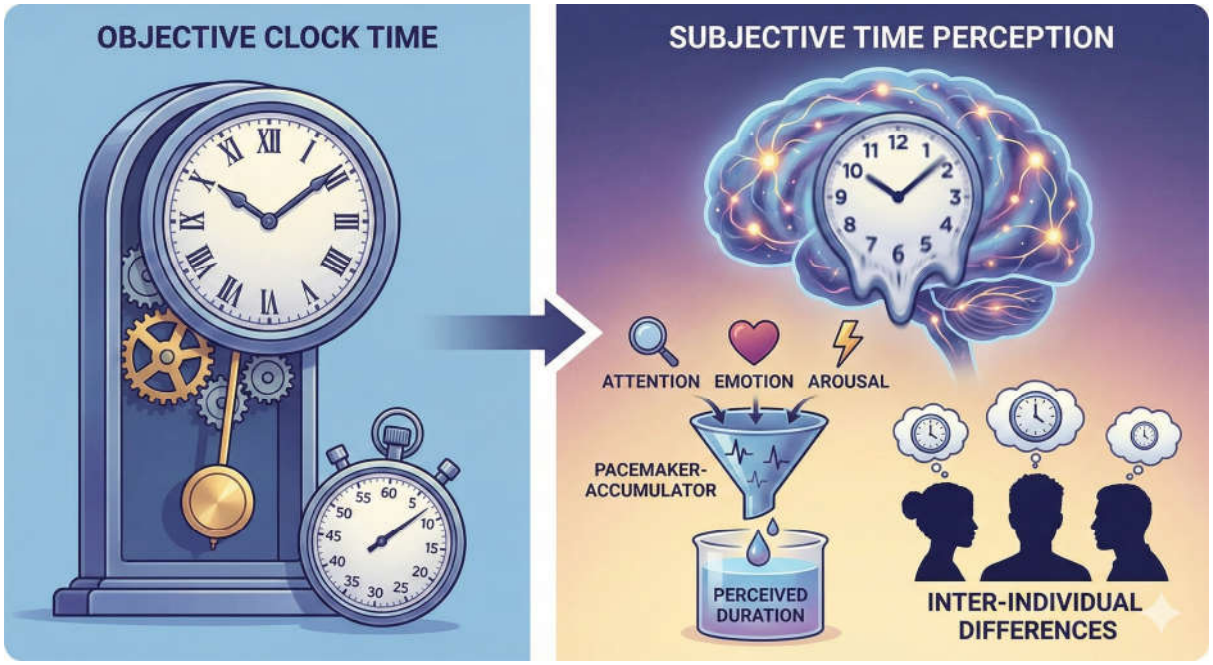

Figure 1. The Cognitive Construction of Subjective Time

Classical models of time perception, particularly pacemaker–accumulator frameworks, propose that temporal judgments arise from the accumulation of neural pulses regulated by attentional gating mechanisms [3]. Variations in pulse rate or attentional control can accelerate or decelerate perceived time, producing distortions in duration estimation [8]. Consequently, identical objective intervals may be experienced differently depending on cognitive state, task demands, or individual differences.

Empirical research has consistently demonstrated substantial inter-individual variability in time estimation accuracy [9,10]. These differences are not merely random fluctuations but reflect stable perceptual tendencies shaped by cognitive control, task engagement, and internal timing dynamics [7]. Despite extensive theoretical exploration, translating these insights into precise and objective measurement of subjective time perception remains methodologically challenging [10-12].

1.2 Time Compression and Time Expansion

Two prominent distortions in subjective time perception are **time compression** and **time expansion**. Time compression occurs when an interval is perceived as shorter than its actual duration, resulting in premature termination of timing tasks. In contrast, time expansion refers to overestimation of elapsed time, leading to delayed responses [6].

Cognitive and attentional models associate time compression with reduced attention to temporal monitoring, often occurring during deep task immersion, divided attention, or high cognitive load [8]. Time expansion, conversely, is linked to heightened temporal awareness, vigilance, emotional arousal, or anxiety [12]. These opposing distortions reflect variations in internal clock dynamics and attentional control rather than random measurement noise.

Although compression and expansion effects are widely reported across experimental paradigms and clinical populations, most studies analyze time estimation error as a continuous variable without formal categorical classification. This limits the identification of stable perceptual patterns and complicates comparison across studies and populations.

1.3 Limitations of Existing Measurement Approaches

Traditional methods for assessing subjective time perception—including verbal estimation, reproduction tasks, and questionnaire-based measures—are subject to multiple methodological biases [10–12]. Verbal estimation depends heavily on numerical cognition and memory, while reproduction tasks often permit counting strategies or rhythmic pacing that contaminate internal timing processes [11, 12]. Questionnaire-based approaches lack objective temporal grounding and primarily capture retrospective judgments rather than real-time perceptual experience.

Software-based timing tasks improve experimental control but introduce visual feedback, display latency, and device-dependent variability [12]. Such factors may enable strategic compensation and obscure genuine internal timing behavior. Collectively, these limitations underscore the need for objective, feedback-free measurement systems capable of isolating endogenous timekeeping mechanisms [13].

1.4 Rationale for a Hardware-Based Classification Approach

A dedicated hardware-based timing instrument offers distinct methodological advantages by enabling precise internal time recording while minimizing external cues and feedback [14-16]. By decoupling time measurement from visual displays and software latency, such systems allow a more direct assessment of internal timing mechanisms.

The **Human Concentration Counter (HCC)** was developed to address these methodological requirements [1]. Its hidden-display design suppresses visual feedback during timing tasks, compelling participants to rely solely on internal temporal perception. This approach strengthens construct validity and reduces strategic bias.

Importantly, hardware-based measurement enables **threshold-based classification** of subjective time perception. By defining quantitative error limits, individual differences in time estimation can be transformed from continuous noise into meaningful perceptual categories, facilitating systematic classification into Neutral, Compression, and Expansion patterns [1].

1.5 Objectives of the Study

The present study aims to:

1. Quantify subjective time estimation error using objective measurements from the HCC.
2. Classify individuals into Neutral, Compression, and Expansion time perception patterns using predefined %TE thresholds.
3. Examine the distribution and prevalence of these patterns within a large adult sample.
4. Statistically validate the separation between perceptual categories.
5. Demonstrate the methodological utility of a hardware-based classification framework for subjective time perception.

2. Materials and Methods

2.1 Study Design

An experimental, cross-sectional design was employed. Participants performed a prospective time estimation task for a 60-second target duration under controlled laboratory conditions. Objective time was recorded internally by the HCC while visual feedback was fully suppressed.

2.2 Human Concentration Counter (HCC)

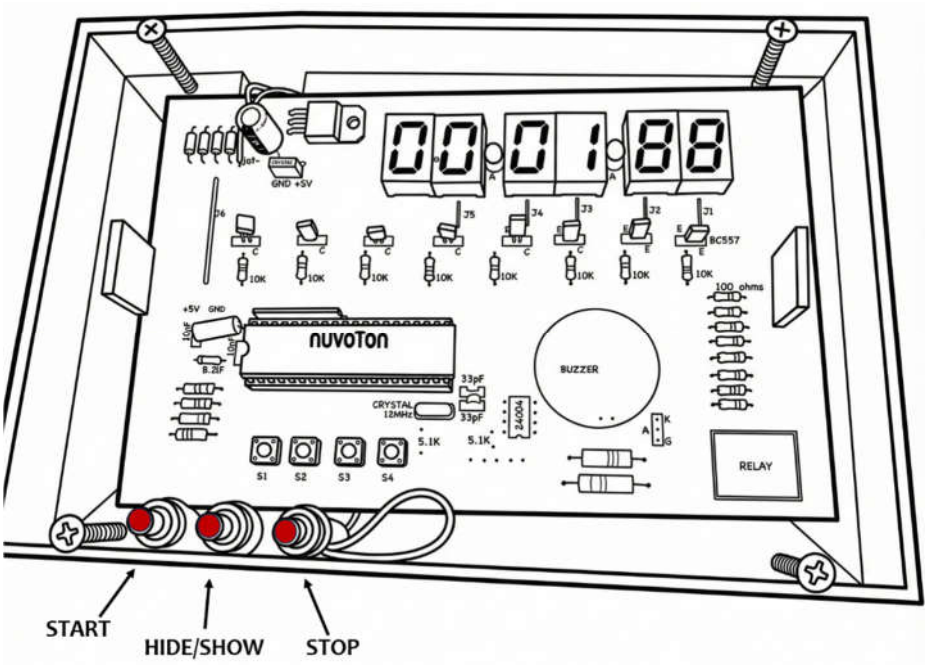

Figure 2 Schematic diagram of HCC Instrument

The HCC is an embedded timing device equipped with a high-precision internal clock and a hidden-display mechanism [1]. During task execution, all visual output is disabled, while internal time counting continues uninterrupted. Time values are revealed only after trial completion, preventing strategic adjustment.

2.3 Participants

A total of 237 adult participants (131 females, 106 males) were included. Participants were recruited from academic and community settings. Inclusion criteria required normal or corrected vision and comprehension of task instructions. Individuals with prior exposure to the HCC or professional timing experience were excluded.

2.4 Experimental Procedure

Participants were instructed to estimate a 60-second interval without counting or using rhythmic strategies. Each trial began with activation of the HCC, followed by hidden-display timing. Participants terminated the trial when they believed 60 seconds had elapsed. Multiple trials were conducted per participant, and mean values were used for analysis.

2.5 Recorded Variables

For each participant and each experimental trial, a set of core variables was systematically recorded to enable precise quantitative analysis of subjective time perception. These variables were derived directly from the Human Concentration Counter (HCC) and were structured to facilitate objective–subjective time comparison.

- **Objective Time (OT):** Actual elapsed time recorded by the HCC.
- **Subjective Time (ST):** Target duration (60 s).
- **Time Difference (TD):**

$$\boldsymbol{TD = OT - ST}\ second$$

A positive TD value indicates that the participant terminated the trial earlier than the target duration (time compression), whereas a negative TD value indicates termination after the target duration (time expansion).

Percentage Time Error (%TE):

To standardize time discrepancy across participants and trials, Percentage Time Error was computed as:

$$\%\boldsymbol{TE} = \frac{(\boldsymbol{OT-ST})}{\boldsymbol{ST}} \times 100\ \%$$

This normalized metric enabled direct comparison of subjective time distortion independent of absolute duration and formed the primary basis for classification into Neutral, Compression, and Expansion patterns.

2.6 Classification Criteria

To systematically classify subjective time perception patterns, participants were grouped based on their **mean Percentage Time Error (%TE)**, which quantifies the difference between the objectively recorded time and the intended target duration. This classification distinguishes whether an individual's internal sense of time closely matches, runs faster than, or runs slower than objective clock time.

- **Neutral:** |%TE| ≤ 5%
- **Compression:** %TE < −5%
- **Expansion:** %TE > +5%

Neutral Time Perception was defined as relatively accurate internal timing, where participants' estimates closely matched the actual duration. Individuals whose mean %TE fell within ±5% of the target duration (|%TE| ≤ 5%) were classified as **Neutral**. This category represents individuals whose internal timekeeping is well calibrated, indicating balanced attention to temporal information without systematic distortion.

Time Compression was identified when participants consistently underestimated the elapsed duration, terminating the timing task earlier than the actual target time. Participants with mean %TE values less than −5% were classified as Compressors. In practical terms, this pattern reflects a subjective experience in which time appears to pass more quickly than it actually does, often associated with reduced attention to temporal monitoring or increased cognitive absorption.

Time Expansion was identified when participants consistently overestimated the elapsed duration, terminating the task later than the target duration. Participants with mean %TE values greater than +5% were classified as Expanders. This pattern reflects a subjective experience in which time appears to pass more slowly, commonly associated with heightened awareness of elapsed time or increased temporal monitoring.

The Neutral, Compression, Expansion pattern classification framework of time perception represents a central methodological contribution of the present study. By applying clear, objective error thresholds to hardware-recorded time estimates, this scheme enables reproducible and intuitive identification of subjective time perception patterns. Importantly, it transforms continuous estimation error into meaningful perceptual categories, providing a robust foundation for subsequent statistical analysis, interpretation, and comparison across studies.

2.7 Statistical Analysis

Statistical analysis was performed to examine variability in subjective time perception and to validate the proposed classification framework based on Human Concentration Counter (HCC) measurements. For each participant, mean Objective Time (OT) and Percentage Time Error (%TE) were calculated across trials. Descriptive statistics, including mean and standard deviation (SD), were computed for the overall sample and for each time perception category (Neutral, Compression, and Expansion).

Group differences in subjective time estimation were assessed using one-way analysis of variance (ANOVA), with perception category as the independent factor and %TE as the primary dependent variable. Objective Time (OT) was additionally examined to support interpretation of temporal estimation behavior. Statistical significance was evaluated at an alpha level of $p < 0.05$. All analyses were conducted using standard statistical software, and results were reported using appropriate test statistics and graphical representations.

3. Results

3.1 Distribution of Time Perception Categories

Among the **237 participants** included in the analysis, **99 individuals (41.8%)** were classified as exhibiting **Neutral** time perception. In contrast, **79 participants (33.3%)** demonstrated **Time Compression**, characterized by systematic underestimation of the target interval, while **59 participants (24.9%)** exhibited **Time Expansion**, reflecting overestimation of elapsed

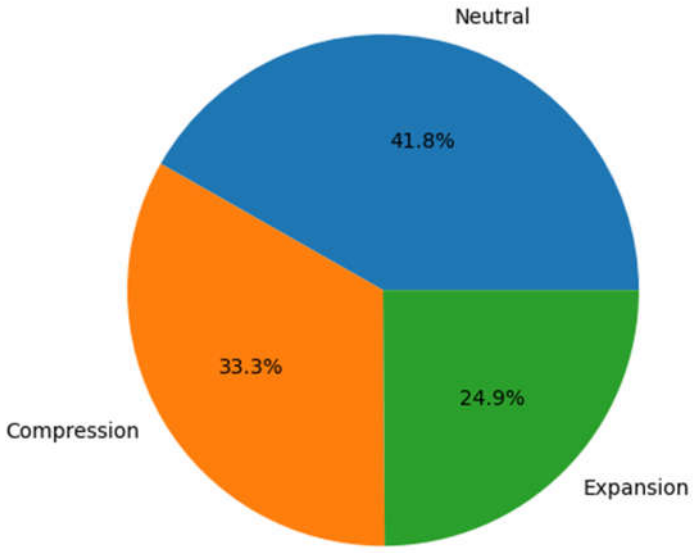

Figure 3 Distribution of Subjective Time Perception Categories

time. Overall, **58.2% of participants displayed systematic distortion of subjective time perception**, indicating substantial inter-individual variability in internal timing behavior.

3.2 Gender Distribution

Gender-wise analysis revealed distinct patterns across time perception categories. The **Compression group** was predominantly female, with women comprising approximately **77%** of this category. In contrast, the **Expansion group** showed a near-equal representation of females and males. The **Neutral group** exhibited higher male representation, with males accounting for approximately **60%** of participants. These distributions suggest gender-related tendencies in subjective time perception within the studied sample.

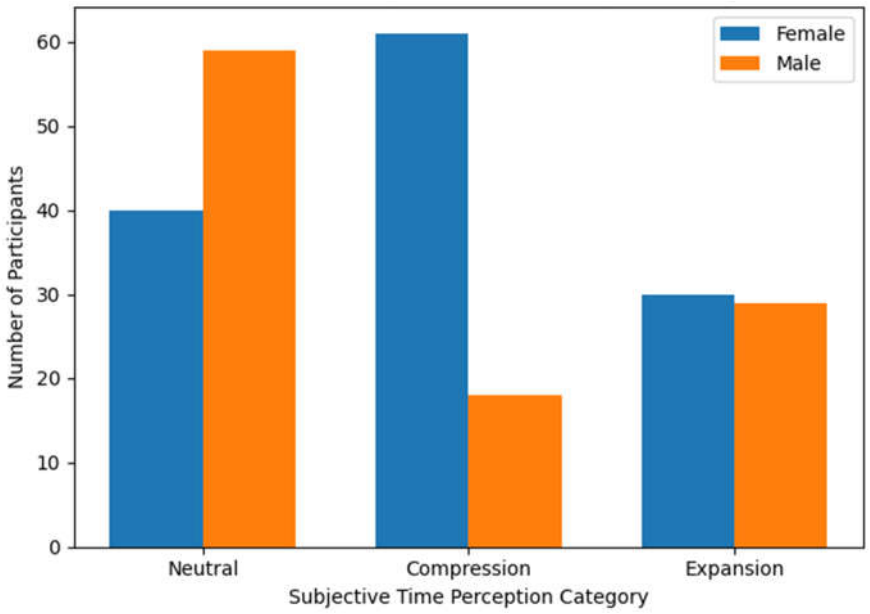

Figure 4 Gender wise Distribution of Subjective Time Perception Categories

3.3 Descriptive Statistics by Category

Descriptive statistics revealed clear quantitative differences in subjective time estimation across the three perception categories. Participants classified in the **Compression** group showed substantial underestimation of elapsed time, with a mean Percentage Time Error (%TE) of **−23.70 ± 15.23%** and a corresponding mean Objective Time (OT) of **45.78 ± 9.14 s**. The **Neutral** group demonstrated near-accurate temporal judgment, exhibiting a mean %TE of **−0.23 ± 2.80%** and an average OT of **59.86 ± 1.68 s**. In contrast, the **Expansion** group overestimated elapsed time, with a mean %TE of **+14.31 ± 13.36%** and a mean OT of **68.58 ± 8.01 s**. These results indicate minimal overlap between categories and support the validity of the threshold-based classification framework.

3.4 Group-Wise Statistical Comparison

One-way analysis of variance (ANOVA) revealed a **highly significant effect** of time perception category on Percentage Time Error (%TE) (**$F = 207.52$, $p < 1 \times 10^{-52}$**), confirming robust and clear separation between the Neutral, Compression, and Expansion groups.

3.5 Inter-Individual Variability

The wide dispersion of Objective Time (OT) and Percentage Time Error (%TE) values across participants indicates the presence of stable inter-individual differences in internal timing mechanisms, rather than random or task-induced estimation error.

4. Discussion

The present findings demonstrate that subjective time perception can be objectively and reliably classified into **Neutral, Compression, and Expansion** patterns using a hardware-based measurement approach. The Human Concentration Counter (HCC), by eliminating visual feedback and external temporal cues, enabled isolation of internal timing mechanisms and revealed distinct perceptual orientations among participants. Time Compression was

characterized by systematic underestimation of elapsed duration, consistent with reduced allocation of attention to temporal monitoring or increased cognitive absorption. In contrast, Time Expansion reflected overestimation of duration, likely associated with heightened temporal awareness or sustained monitoring of elapsed time. The Neutral group exhibited near-accurate temporal judgment, representing optimal internal calibration of subjective time perception.

The exceptionally strong statistical separation between categories supports the interpretation of subjective time perception as a **patterned cognitive trait** rather than a continuous distribution of random estimation error. The clear divergence in Percentage Time Error across groups suggests that internal timing behavior reflects stable perceptual tendencies linked to attentional control and cognitive state. By operationalizing time perception through quantitative thresholds and objective measurement, the present study advances methodological rigor in temporal cognition research and provides empirical support for categorical models of subjective time perception.

5. Conclusion

This study establishes a robust, hardware-based framework for the quantitative classification of subjective time perception. Using the Human Concentration Counter (HCC), precise and feedback-free measurement of internal time estimation revealed stable time perceptual patterns of Neutral, Compression, and Expansion. Notably, only **41.8%** of participants demonstrated near-accurate temporal judgment, while a substantial **58.2%** exhibited systematic distortion of subjective time perception, emphasizing the non-uniform and cognitively modulated nature of human temporal experience.

The distribution of perceptual patterns and associated demographic tendencies further underscore the role of attentional and cognitive factors in internal timekeeping. Time Compression, characterized by pronounced underestimation of duration, was predominantly observed in female participants (**~77%**), whereas the Neutral group showed higher male representation (**~60%**), suggesting potential gender-related differences in temporal attention and perceptual calibration. These findings align with theoretical models proposing that human duration judgments are dynamically influenced by attentional allocation, concentration, emotional state, and arousal.

Overall, the proposed Neutral–Compression–Expansion classification model provides a reproducible and objective foundation for investigating individual differences in internal timekeeping. By combining quantitative thresholds with hardware-based measurement, the present framework offers a valuable methodological tool for future research examining cognitive, emotional, and contextual influences on human temporal perception.

6. References

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